MODELLING DECISION-MAKING FROM POPULATION DATA: HOUSEHOLD INCOME FORCING

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This paper presents a new approach to model household financial decision-making by using population data. Termed *household income forcing* this analytical framework requires the economy to be divided into regions based on cost of supplies and local taxes, and households to be separated into economic groups based on their cost of living and financial circumstances. It tests household *financial forcing* by calculating the difference between household income and running costs, and it evaluates *perceived forcing* by comparing household income to that of other households. The set of financial decisions a household can make under a given income forcing, which is the combined effect of financial forcing and perceived forcing, can be implemented in economic models by using surrogate models of actual household financial behaviour. The framework of household income forcing will enable welfare to be quantified using the binary measure of households moving above or below the poverty threshold and will quantify the income deficit across a full range of economic groups for a given fiscal and monetary policy or economic event.

1   INTRODUCTION

1.1 ECONOMY DYNAMICS

This paper is part of the *Economy Dynamics* series defining a new approach to macroeconomic analysis and forecasting. The different elements of Economy Dynamics are summarised in Figure 1 and an overview is provided by Maybury (2020). The methodology has been developed independent of current economic theories. The concept has been based on observations of the decision-making and financial circumstances of businesses and households and defining the interdependency between consumers and suppliers. The models of the Economy Dynamics framework have been expressed using computational mathematics from engineering and data science. The framework architecture is based on recent advances in software architecture to automate complex analytical processes. The software architecture will enable any economic theory that fulfils model requirements of the Economy Dynamics framework to be tested.

This paper presents a new approach to model the household financial decision-making process. It is an analytical framework to capture the probability of household financial actions occurring under a given set of economic conditions. Termed *household income forcing* it has two parts: *financial forcing* and *perceived forcing*. Financial forcing is the difference between household income and running costs and perceived forcing is a comparison of the household income with that of other households. The household economic conditions are determined by their income forcing and the probability of financial actions occurring are captured from population data by using surrogate modelling methods. The probability of a financial action can then be modelled under different household financial conditions by using the revised household income forcing values when testing household decision-making probabilities using the surrogate models. The term financial forcing is equivalent to the

common meaning of disposable income, being the money available to spend at the discretion of the household after all living costs have been deducted.
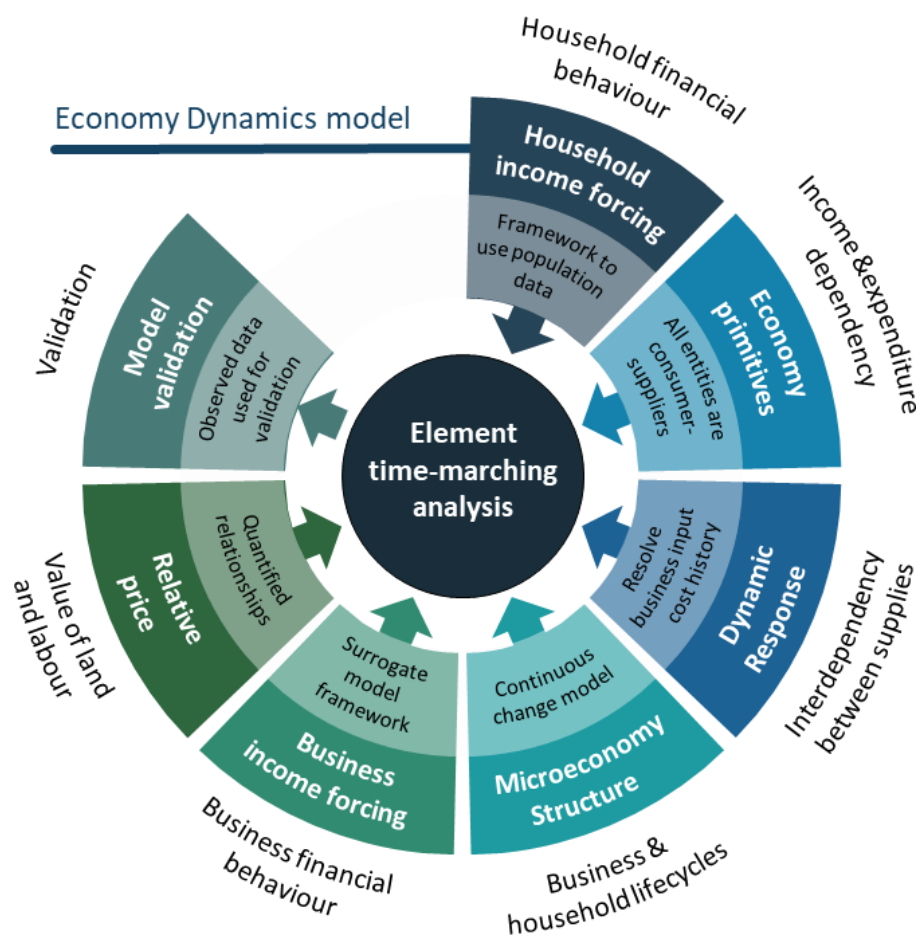

Figure 1. Economy Dynamics infographic

The Economy Dynamics requirements for modelling household financial behaviour are to explain, and thereby model, variation in financial behavioural patterns between household groups. It must also predict the aggregate consumption of different types of goods, services and assets within different regions of an economy for the different household groups. This requirement can be quantified by testing the household decision-making model against the behavioural patterns of population data within different economic regions. Any analytical methods that meet the household behaviour modelling requirements can be substituted for the methodology proposed here within the Economy Dynamics framework.

1.2 THE NEED FOR THIS PAPER

Currently, utility theory is taught in economics classrooms as a fact. This theory is the belief that the benefit or enjoyment gained from consuming goods and services affects their price. Strictly, the theory is attempting to explain price and not consumer behaviour, but unfortunately explains neither.

Utility functions are a branch of mathematics devoted to decision-making. Here, a correlation between a prescribed theoretical function of consumer choice and historical consumer data are fitted to a wide range of consumer behaviours. The problem with claiming that utility functions are evidence

of utility theory is the inability to demonstrate that these functions show that consumer behaviour affects price and not that price affects consumer behaviour. The latter is observable as any closing down sale attests to, whereas the former is not, as the theory does not include the role of retailers in setting the price.

Owing to a mathematical phenomenon known as spurious variable correlation, whereby the same correlation is achieved with cause and effect modelled the wrong way round, statistical correlation cannot help us determine what utility functions demonstrate. Instead, we need alternative logic. So, following the principle of Occam's razor – that the simplest explanation is most likely correct – then we must assume that the observable explanation takes precedence over the unobservable explanation.

Although a statistical method cannot resolve this conundrum, an applied mathematics method could. Moreover, the methodology of Economy Dynamics will be able to determine to what extend the behaviour of consumers affects price. However, this requires modelling the observable mechanisms, which requires utility theory to be rejected as a general explanation of the pricing of goods. Note the word general. There may be secondary effects, such as a retailer dropping their price if they fail to sell goods, but this is not what Utility Theory is claiming.

2   COST OF LIVING

A universal aspect of all economies is the minimum value of money needed to acquire essential supplies to avoid psychological or physical suffering. The Joseph Rowntree Foundation has proposed a minimum income standard *MIS*, which is the lowest income needed to maintain basic human dignity (Bradshaw et al., 2008 and Hill et al., 2016). This benchmark income is identified by determining the minimum basket of goods and services required to live and participate within a community, specified by people from the community who are guided in their choices by welfare experts.

If we consider the cost price of output supplies to be the cost side to financial decisions of a business, then the minimum cost to run a household must drive domestic financial decisions. The MIS is not the cost side of the financial forcing for the whole population, as it is the absolute minimum cost. However, there is an emotional burden on every household to maintain their current living standard, which has an associated minimum running cost. Households with a high level of living standard can downsize, but this will come with an emotional stress or other constraining influences. A hypothesis would be that downsizing will be resisted until the transition in living standard is a financial forcing imperative or is planned due to a change in life circumstance, such as downsizing after retirement. Under a given set of adverse financial circumstances it is possible to continue downsizing down to the MIS. The MIS is the poverty threshold, below which significant physical and mental deterioration is likely to be suffered.

3   HOUSEHOLD ECONOMIC GROUPS

A household given the financial opportunity may choose to increase their living standard. The change to the living standard may include committing to regular payments to maintain that lifestyle, which becomes the cost side of the new financial forcing. The change to living standard may include capital and interest loan repayments to buy a large house in a prosperous neighbourhood, loan interest

repayments and capital depreciation costs for driving an expensive car, expenses for premium recreation activities and fees for educating children. If a major life event changes the ability of a household to maintain the living standard, such as redundancy or a divorce, the household may be forced to adopt a lower living standard, such as moving to a less desirable neighbourhood, selling the car, giving up expensive recreation activities and using public funded schools.

This paper uses the economic group index i_e to distinguish between household living standards. Each economic group will be represented by a basket of goods and services that are regular outgoing costs necessary to maintain the given living standard, such as housing cost, the purpose and cost of unsecured borrowing, the cost of transport for leisure and commuting, spending on food and drink, spending on entertainment, fees for educating children and wages for domestic services, such as cleaning and gardening. These must be running costs that the household cannot cut without a financial forcing outweighing the household emotional attachment to the supply. The economic group index also represents a probability distribution for the financial response of a household to a given income forcing. Dividing households into economic groups (and further into subgroups, see Section 5.1) restricts the range of potential financial decisions for a given income forcing, facilitating a probabilistic approach to modelling household financial behaviour.

To identify different levels within the economic groups we can consider three hypothetical households representing a low, medium and high living standard. An illustration of these hypothetical households is shown in Figure 2. The following paragraphs represent a potential economic scenario relating to the low, medium and high living standard households respectively.

The low living standard household has no assets; they are renting a house and do not have sufficient income to invest in a pension. The main income provider is a low skilled shift-worker and the other is a part-time cleaner. They live in a small terraced house where their children share a bedroom and the only reception room is a small sitting room that requires the children to sit on the floor when eating and watching television. The children attend the local public funded school, which is rated as "requiring improvement" in the government inspection report. They do not own a car. They use bank overdrafts and credit card borrowing to balance monthly demands on cashflow. Loss of employment of the main income provider, severe ill health, divorce, or birth of another child could send them below the MIS. Being made homeless could be the consequence of an adverse event occurring (see for example Crane et al., 2005). An unexpected bill such as a boiler repair or delays in being paid benefits or wages could force them into a poverty trap (see for example Goulden, 2010).
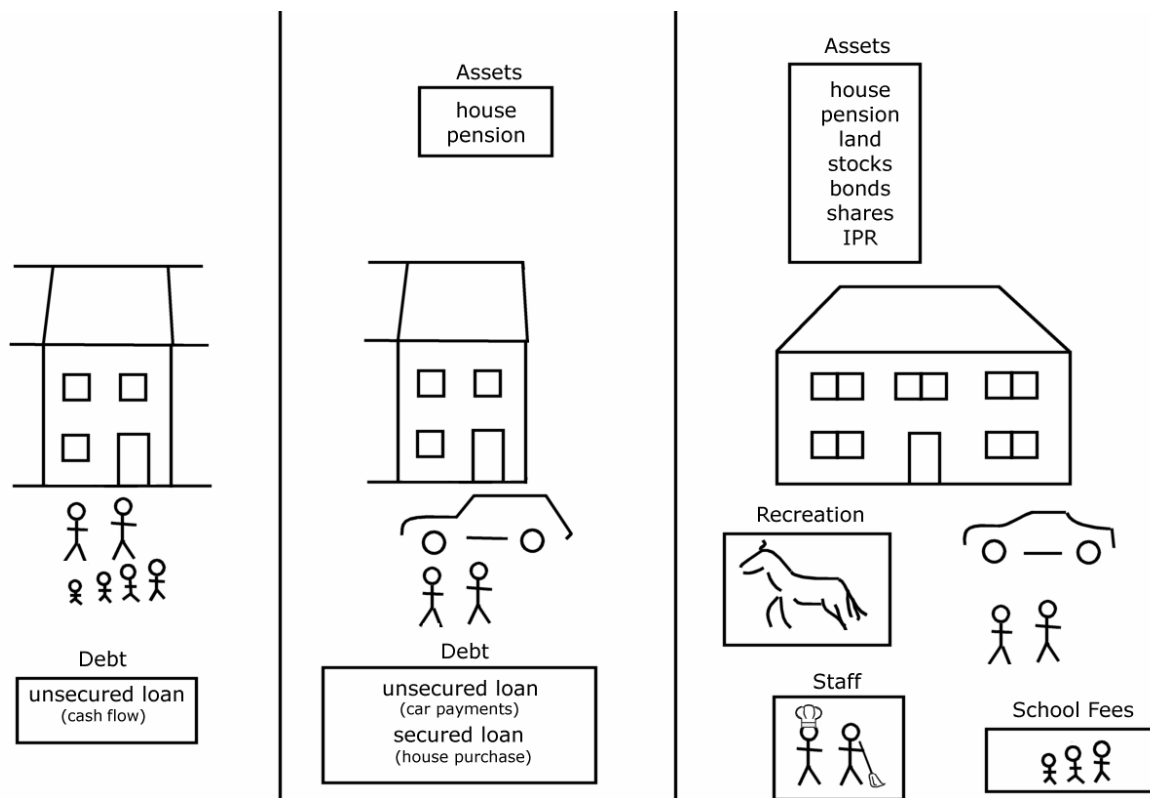
Figure 2. Illustration of hypothetical low (left), medium (middle) and high (right) living standards.

The medium living standard household are homeowners with a secured loan against their house and they make monthly contributions to a private pension scheme. The main income provider is self-employed in their skilled trade and the other is a care worker. They live in a small family semi-detached house, which has three bedrooms and two receptions rooms. The reception rooms are used as a sitting room and dining room. The couple have an unsecured loan to spread payments on a van used for the trade business. They plan to start a family and the care worker will become the primary carer for the children. They live within the catchment of a public funded school, which was described as "good" in the government inspection report. They are financially secure against most unforeseen events for a short period of time, except for debilitating ill health of the main income provider. A 15% drop in demand for the trade services would result in the household being unable to keep up with loan payments. If the couple separate after starting a family the two households will be close to the MIS.

The high living standard household are homeowners without any debt. They have a substantial private pension fund and they also own a holiday home, which they rent out for additional income. The main income provider is a partner in a professional firm and the other works freelance in the creative industries. They live in a large detached period house that has seven bedrooms and five reception rooms. The reception rooms are used as a sitting room, dining room, study, home cinema and home gym. They have large regular outgoing costs including fees for educating their children at a boarding school and staff wages to maintain and keep the house and large grounds. Other key outgoing costs are commuting, keeping horses and skiing holidays. They are secure against most unforeseen events. Being made redundant is unlikely and they have additional income from renting their holiday home and royalties from previously published creative works. A divorce would require a change to the living standard but could be offset by a secured loan against one of their properties. The financial decisions

of this couple are likely to be made against a perceived forcing as the couple have not experienced negative financial forcing for 20 years, since the main income provider achieved their professional qualifications and started their career.

4 INCOME FORCING

The financial decisions of households will depend upon the difference between the household income and the running cost. If there is an income deficit, resulting in a negative financial forcing, the household must either reduce living costs or find a way to increase income. If there is an income surplus, resulting in a positive financial forcing, the household may have the opportunity to raise their living standard, purchase luxury and premium consumable items, pay off debt, purchase assets or increase pension contributions.

In addition to a financial forcing there is a perceived forcing that is not related to a material impact on the household living standard but evokes a financial action. The perceived forcing could be a comparison of income with the previous year or comparison of income with a colleague, or comparison of salaries for similar employment in a different region of the economy. Under neutral or positive financial forcing there may be negative perceived forcing that leads to a different set of decisions.

This section and its subsections outline the mathematical approach to determining the financial forcing, the perceived forcing and the framework required to develop probability functions for the financial decisions of households within the economic subgroups. The framework requires the economy to be separated into distinct geographical regions based on changes to the cost of supplies or local tax. These regions are known as *economy elements* and are identified by index i_α.

The household population of the economy elements are divided in groups that have a similar standards of living i_e and are further subdivided by likely financial characteristics and behaviour, based on composition of the household i_h, the skill category of the main income provider i_s, the stage of family and working life based on the age of the main income provider i_a, their minority grouping i_m and their parental living standard i_{ep}. A detailed description of the model indices is provided in Section 5.1. For convenience within the mathematical formulae, the index i_{e+} will be used to represent the household economic group living standard i_e and all subgroups (i_h, i_s, i_a, i_m and i_{ep}). A list of indices and other symbols is shown in Section 6.1.

The household financial decision-making process is shown as a flow diagram in Figure 3. The process starts by evaluation of the household financial forcing, which is the difference between household running costs, including the savings of households fulfilling their own supplies, and the household income. If there is negative financial forcing (income deficit) then an unsecured loan will be used to bridge the cash-flow gap. If the loan is refused the household will be forced to downgrade their living standard. If the living standard is already at the MIS the household will be driven into poverty. Alternatively, if there is positive financial forcing (income surplus) or the household can obtain unsecured loans to bridge the gap in cash-flow then the household perceived forcing must be tested. The combination of financial forcing and perceived forcing will be used to determine household financial decisions. The financial decision will lead to a change in spending behaviour and income sources, including potentially selling assets and seeking new work.
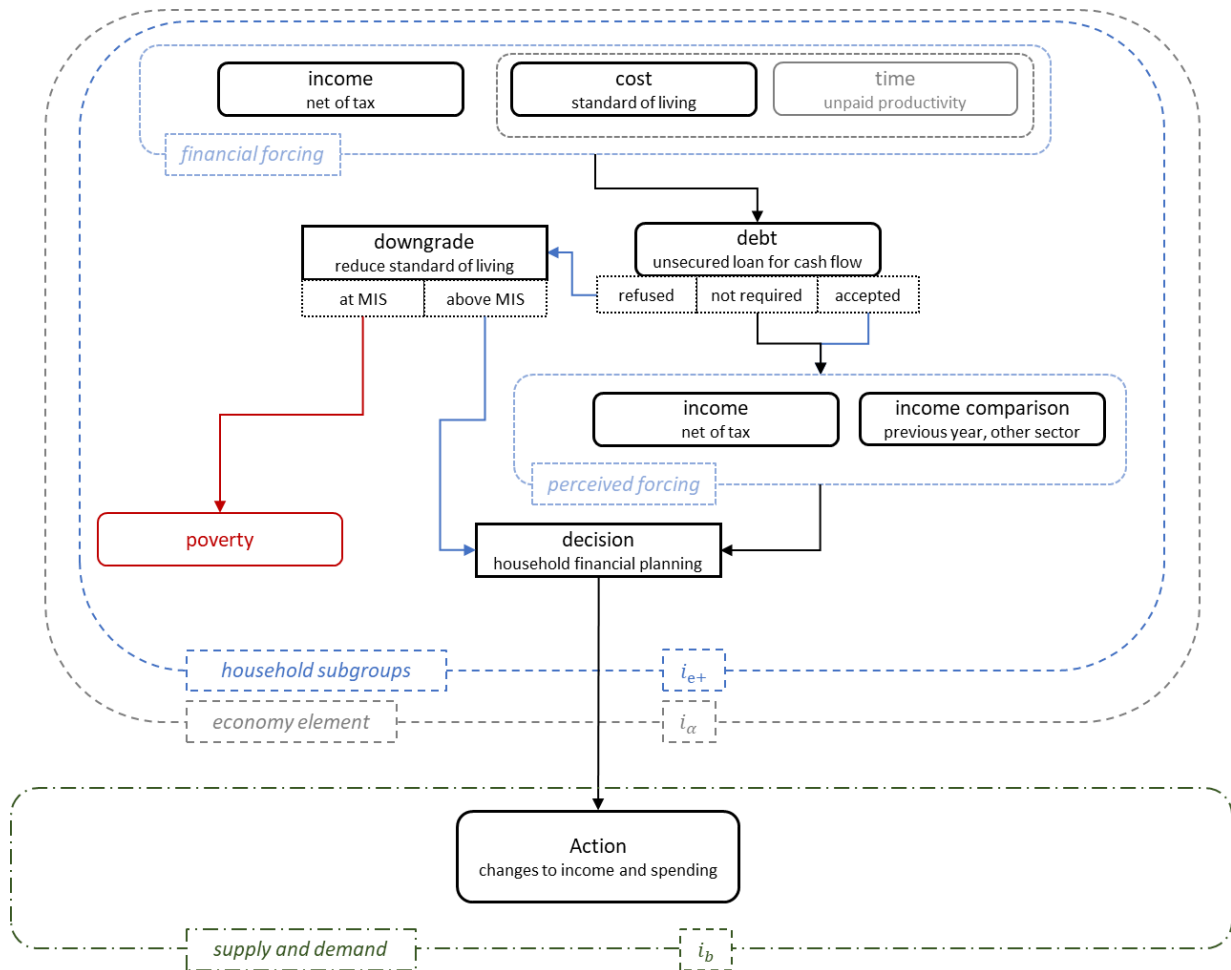
Figure 3. Financial forcing impact on decision-making for households

4.1 HOUSEHOLD COSTS

The household running costs will depend upon the economy element i_α, the economic subgroup i_{e+} and the date represented by the simulation time index i_t. The running cost will be calculated by summing the cost of purchasing the basket of goods and services for the given living standard. The indices for the basket of goods and services that form the living standard $j_{b\,(i_{e+})}$ will correspond to an index of the basket of supplies of the economy i_b. Details of the indexing of goods and services for an economy model is discussed in Section 5.2.

To determine whether interest payments on debt should be added to the cost side of the financial forcing or removed from the income side depends on the nature of the debt. Secured loan repayments and property rents are equivalent household commitment costs. The choice and availability of these options will depend on the household economic subgroup. Therefore, interest and capital repayment of secured loans should be added to the cost side of financial forcing.

Unsecured loans to spread purchase costs over time are a practical mechanism to replace expensive depreciable assets that are associated with a given living standard, such as a fridge freezer or car. The use of loans to spread payments, the items purchased with these loans and the type of loan (i.e. arranged, unarranged or prior credit agreement) will depend on the household subgroup and so too

will the relative interest payment costs. Therefore, interest repayments and asset depreciation are added to the cost side of financial forcing.

It is proposed that surrogate modelling type methodologies are used to determine debt payment costs by analysing population data. Surrogate modelling methodologies are discussed in Section 6.2. Determining the household debt payment costs are discussed in Section 6.2.1.

The household running costs will be affected by the allocation of household time and whether the household fulfils its own goods and services requirements. The running costs will also be affected by the purchasing of goods and services from the undeclared economy, which does not pay tax. The allocation of unpaid productive time to reduce living costs and the propensity to purchase supplies from the undeclared economy will be functions of the household economic subgroup i_{e+}. Determining the equivalent items in the basket of goods and services fulfilled by the household themselves is discussed in Section 6.2.2 and supplies purchased from the undeclared economy is discussed in Section 6.2.3. The calculation of household running costs is defined in Section 6.3.1.

4.2 HOUSEHOLD INCOME

The income of a household will depend upon the economy element i_α, the economic subgroup i_{e+} and the date represented by the simulation time index i_t. The household income will be calculated by summing the household paid labour y_{α_L}, benefits y_{α_B}, and income from land assets $y_{\alpha_{A_L}}$, financial assets $y_{\alpha_{A_F}}$, private business stakeholding $y_{\alpha_{A_B}}$ and intellectual property rights $y_{\alpha_{A_{IP}}}$. Household income for paid labour is the combined pay for household labour from declared $y_{\alpha_{L_w}}$ (gross of tax) and undeclared $y_{\alpha_{L_x}}$ (untaxed) paid work. The benefits income for the household can include unemployment and low-income allowances, state paid child benefits, separated partner child maintenance support and state pensions. It is proposed that surrogate modelling methodologies are used to determine the income for labour, assets and benefits based on analysing population data, which is discussed in Section 6.2.4.

The income from assets has been separated by the general characteristics of the asset group. Land assets $z_{\alpha_{A_L}}$ include land, buildings, infrastructure and equipment as these are physical resources dependent on land usage of an economy element. Financial assets $z_{\alpha_{A_F}}$ include stocks, bonds and shares in public companies and other goods traded through central markets that do not have physical form. Business assets $z_{\alpha_{A_B}}$ (as distinct from financial assets) are specifically shares (or other form of stakeholding) in a private business, which is an asset that can be accumulated by households through both paid and unpaid effort as well as being bought or sold. Intellectual property $z_{\alpha_{A_{IP}}}$ is distinct from business assets because they represent the household creation of a single good, which may then be sold or licensed. It is proposed that surrogate modelling methodologies are used to determine the distribution of assets based on analysing population data, which is discussed in Section 6.2.5.

The effect of debt on household running costs has been discussed in Section 4.1. However, interest on unsecured loans to bridge cash-flow gaps for consumable costs is not a cost of the living standard as this debt is not a necessity but a result of circumstance. Therefore, interest payments of unsecured loans for cash-flow are to be removed from the income side of the income forcing and are not to be added to the cost side of the financial forcing. Modelling the costs of cash-flow debt is discussed in Section 6.2.1.

Income tax will vary within the economic subgroups that have a common living standard and must be removed from the income side of the income forcing. Income tax will be calculated based on the household income components and subtracted from the household gross income. The calculation of household income, including the calculation of income tax is defined in Section 6.3.2

4.3 HOUSEHOLD FINANCIAL DECISIONS

The household financial decisions, and external actions imposed upon a household, will depend on the direction and magnitude of the financial forcing $y_{\alpha_{ff}}$ using the definition in Section 6.3.3. An income deficit will need to be bridged using an unsecured loan. Receiving an unsecured loan will depend on household financial eligibility that will be determined by using a surrogate model approach outlined in Section 6.3.4. If the loan is provided, or there is positive financial forcing, the perceived forcing income $y_{\alpha_{pf}}$ must be evaluated following the method defined in Section 6.3.5. The combination of the financial forcing and the perceived forcing for a household within an economic subgroup will have a probability associated with a set of financial decisions relating to purchasing supplies and assets, or selling assets, or seeking new, alternative or additional sources of income. Evaluation of the household financial decisions will require the use of a population data surrogate model methodology outlined in Section 6.3.6.

5 MODEL INDICES

The following section provides guidance on the derivation of indices required for the income forcing analytical framework. There are three subsections that respectively define the household economic subgroups, the basket of goods and services, and the household allocation of time.

5.1 HOUSEHOLD ECONOMIC SUBGROUPS

The household economic group subdividing categories are defined in this section.

5.1.1 SKILL INDEX

The purpose of the skill index i_s is to subdivide the economic group by education, training and type of occupation, which must also distinguish between the relative levels of job security. The index ontology is based on the Office for National Statistics, Standard Occupational Classification SOC (ONS.Gov.UK, 2010) and is shown in Table 1.

Whether a person is in employment does not change their skill index value, therefore this is not a typical socio-economic categorisation. The skill index is a high-level definition compared to the occupation index i_o, as it must group households together, whereas an occupation index will be required to evaluate the economy response to the labour supply and demand characteristics.

The level of job security will have a significant effect on financial decision perspectives, as anyone who has experienced redundancy or is in an environment where redundancy is a threat will have a different attitude to financial risk than those in secure employment. Moreover, people whose income regularly increases, such as those in professional roles in large organisations, are unlikely to experience negative financial forcing unless through an error in financial judgement or through circumstances such as ill health or divorce.

Skill Level	Skill Index	SOC 2010	
Level 4	[1,1]	11	Corporate managers and directors
	[1,2]	21	Science, research, engineering and technology professionals
		22	Health professionals
		23	Teaching and educational professionals
		24	Business, media and public service professionals
Level 3	[2,1]	12	Other managers and proprietors
	[2,2]	31	Science, engineering and technology associate professionals
		32	Health and social care associate professionals
		33	Protective service occupations
		34	Culture, media and sports occupations
		35	Business and public service associate professionals
	[2,3]	51	Skilled agricultural and related trades
		52	Skilled metal, electrical and electronic trades
		53	Skilled construction and building trades
		54	Textiles, printing and other skilled trades
Level 2	[3,1]	41	Administrative occupations
		42	Secretarial and related occupations
	[3,2]	61	Caring personal service occupations
		62	Leisure, travel and related personal service occupations
	[3,3]	71	Sales occupations
		72	Customer service occupations
	[3,4]	81	Process, plant and machine operatives
		82	Transport and mobile machine drivers and operatives
Level 1	[4,1]	91	Elementary trades and related occupations
		92	Elementary administration and service occupations

Table 1. Household skill index adapted from ONS.Gov.UK, 2010

5.1.2   HOUSEHOLD STRUCTURE

The number of adults and children in a household is represented by index i_h, which could range from households with 1 to 6 adults and 0 to 5 children. The composition of the household will affect the living cost and the household income. This index will be particularly important to enable scaling of the living costs to meet the requirements of different household structures. When defining the index bandings, it is important to ensure the population sample sizes of the indexed subgroup is sufficient to allow for meaningful population data analysis.

5.1.3   AGE GROUP CATEGORY

The age group index i_a, based on the age group banding of the main income provider, indicates the different stages in household life and career cycles. This will affect both the household running costs, the income and financial decision making.

5.1.4   MINORITY GROUPING

The minority index i_m of the main income provider may affect the household income, based on the potential for workplace discrimination, and alter the probability of given financial decisions, based on

differences in life experience and perspectives. When defining the minority index on ethnicity, race, religion, sexual orientation, disability and gender identity, it is important to ensure the population sample sizes of the indexed subgroup is sufficiently large for statistical relevance.

5.1.5 PARENTAL ECONOMIC SUBGROUP

The parental economic group index i_{ep} may affect household income as wealthy families could provide financial support to offspring, which would be treated as a component of household benefit income. The likelihood of parental financial support may also affect the willingness to take financial risks, such as becoming a musician or taking an unpaid internship. Similarly, the parental economic group may reflect a likely childhood educational path, such as paying for private education, which remains an important factor in achieving the top jobs (Gov.UK, 2019).

5.2 GOODS AND SERVICES

The goods and services index i_b represents the basket of all supplies traded within the economy, including consumable supplies, depreciable assets, financial products, land, property and equipment assets, private businesses stakeholding, intellectual property and goods and services in the undeclared economy. The index is a computational object that for all supplies defines the supply and demand characteristics, the resolved price and other parameters such as the supply carbon footprint. Further detail of the supplies definition and the supply and demand characteristics are shown in Section 6.1.1, see i_b. The definition of supplies follows a similar ontology to the consumer basket of goods and services defined by the Office for National Statistics (ONS.Gov.UK, 2019 [1] and [2]). However, the basket of supplies must apply to the whole economy, for both declared and undeclared economies, and is shown at the top level in Table 2 and with example subdivisions in Table 3.

Supply superclass	Goods, services, materials, assets, donations
[1,:,:][:,:,:]	Food & non-alcoholic beverages
[2,:,:][:,:,:]	Alcohol, tobacco & recreational drugs
[3,:,:][:,:,:]	Clothing, footwear & personal effects
[4,:,:][:,:,:]	Housing & household services
[5,:,:][:,:,:]	Furniture & household goods
[6,:,:][:,:,:]	Health and social services
[7,:,:][:,:,:]	Transport
[8,:,:][:,:,:]	Communication
[9,:,:][:,:,:]	Recreation, culture and entertainment services
[10,:,:][:,:,:]	Education
[11,:,:][:,:,:]	Restaurants & hotels
[12,:,:][:,:,:]	Land, buildings and infrastructure
[13,:,:][:,:,:]	Financial services, assets and debt
[14,:,:][:,:,:]	Private business stakeholding
[15,:,:][:,:,:]	Intellectual property rights
[16,:,:][:,:,:]	Supply production machinery
[17,:,:][:,:,:]	Livestock and crops
[18,:,:][:,:,:]	Mined and extracted minerals and ores
[19,:,:][:,:,:]	Fuel and energy
[20,:,:][:,:,:]	Mechanical and digital components and parts
[21,:,:][:,:,:]	Software (excluding games)
[22,:,:][:,:,:]	Charitable donations

Table 2. Goods and services index superclass

Supply superclass	[1,:,:][:,:,:]	Food & non-alcoholic beverages
Supply class	[1,1,:][:,:,:]	Bread and cereals
Supply subclass	[1,1,1][:,:,:]	Rice
Supply subclass	[1,1,2][:,:,:]	Flours and other cereals
Supply subclass	[1,1,3][:,:,:]	Bread
Supply subclass	[1,1,4][:,:,:]	Other bakery products
Supply subclass	[1,1,5][:,:,:]	Pizza and quiche
Supply subclass	[1,1,6][:,:,:]	Pasta products and couscous
Supply subclass	[1,1,7][:,:,:]	Breakfast cereals
Supply subclass	[1,1,8][:,:,:]	Other cereal products
Supply distributor	[1,1,7][1,:,:]	1=iB+[Kellogg's UK Ltd]
Supply distributor	[1,1,7][2,:,:]	2=iB+[Weetabix Ltd]
Supply distributor	[1,1,7][3,:,:]	3=iB+[Cereal Partners UK Ltd]
Supply distributor	[1,1,7][4,:,:]	4=iB+[SME Organic]
Supply distributor	[1,1,7][5,:,:]	5=iB+[SME Non-organic]
Retail supplier	[1,1,7][4,1,:]	1=iB+[Tesco Plc]
Retail supplier	[1,1,7][4,2,:]	2=iB+[Asda Stores Ltd]
Retail supplier	[1,1,7][4,3,:]	3=iB+[Sainsbury's]
Retail supplier	[1,1,7][4,4,:]	4=iB+[SME Convenience Store]
Retail supplier	[1,1,7][4,5,:]	5=iB+[SME Ethical Store]
Demand index	[1,1,7][4,5,1]	1=ie+[household economic group ie=11]
Demand index	[1,1,7][4,5,2]	2=ie+[household economic group ie=12]
Demand index	[1,1,7][4,5,3]	3=ie+[household economic group ie=13]
Demand index	[1,1,7][4,5,4]	4=ie+[household economic group ie=14]
Demand index	[1,1,7][4,5,5]	5=iB+[Micro SME bakery]

Table 3. Basket of supplies example index subdivision for bread and cereals food groups.

5.2.1 LIVING STANDARD BASKET OF GOODS AND SERVICES

The MIS basket of goods and services for each economy element could be defined following the Joseph Rowntree Foundation methodology (Bradshaw et al., 2008). A similar systematic approach will be required to define the basket of goods and services for the other economic groups i_e, adjusted by the composition of the household i_h and the age of the main income provider i_a and the minority group of the main income provider i_m as a minimum. The basket of goods would be represented by $j_{b\,(i_\alpha, i_{e+})}$ where the index values j_b are specific to the different economic subgroups i_{e+} used to define the basket of goods which must be a subset of the economy basket of goods and services i_b.

There are methods to scale household living costs from the costs of living for a single person to the costs of living for households with more than one adult, such as defined by OECD.org (2019). However, for Economy Dynamics modelling, to enable the evaluation of the economy response to the supply and demand characteristics of all economy elements it will be necessary to establish the change in volume and indices of the basket of goods relative to the household composition and household life cycle stage.

5.3 HOUSEHOLD PRODUCTIVE TIME ALLOCATION

The indices for the allocation of household time are defined and the effect on income and running costs are discussed in the following subsections.

5.3.1 PAID TIME ALLOCATION

The total hours that are declared in paid work for a household within a time interval is represented by index i_w and those that are undeclared, resulting in untaxed income, is represented by index i_x. The indices will need to distinguish between one person in full-time employment and two people in part-time employment. In addition, it is likely that adult offspring and other temporary adult residents, will leave the household given suitable financial circumstances. Therefore, the index will need to treat the paid time of an adult non-home maker differently to the adult(s) responsible for the household, as the non-home makers will not support household living standard long-term.

5.3.2 UNPAID TIME ALLOCATION

The unpaid time allocation index i_u is the proportion of time a household spends in unpaid productive activities. Unpaid time may reduce household running costs or lead to an increase in household income in the future. Examples of unpaid activities that reduce household running costs include childcare, house maintenance, cooking meals and repairing clothes. Examples of unpaid productive time leading to higher future income includes, attending training courses, unpaid work experience, turning a hobby into a business, and creating copyrighted artistic works or patentable inventions.

The unpaid time allocation index i_v is the proportion of time a household spends in charitable and other voluntary work, which will not affect the financial forcing. However, time spent on voluntary work may affect the economy response to the net employment supply and demand characteristics and should be considered in dynamic models of the economy.

6 MODEL FUNCTIONS

This section provides the mathematical definitions for the income forcing analytical framework. The subsections respectively define the symbols, discuss the surrogate models of household financial demographics and present the equations to determine the household income forcing and probable financial decisions.

6.1 SYMBOLS

This paper is in a series that defines the Economy Dynamics framework, a new approach to macroeconomic forecasting (see Maybury, 2020). All the papers within the series use a set of symbols defined specifically to meet the new framework ontological requirements. The symbols used in this paper are listed below.

6.1.1 INDICES

i_α economy element index for household population demographics

i_a age category of the main income provider of household

i_b economy basket of supplies index, which includes assets. It is a computational object. A subset of the object is represented by $i_b[i_{1b}, i_{2b}, i_{3b}][i_{4b}, i_{5b}][i_{6b}]$, where

         i_{1b} is the supply superclass, e.g. food | clothing | furniture | education | … ;

i_{2b} is the supply class, e.g. from food superclass cereals | meat | fish |... ;

i_{3b} is the supply subclass, e.g. from cereals class bread | rice | pasta | ... ;

i_{4b} is the distributor index, which is a subset of i_{B+};

i_{5b} is the retailer index, which is a subset of i_{B+};

i_{6b} is the consumer index, which is a subset of i_{e+} and i_{B+};

i_{B+} business subgroup.

i_C charity subdivision of the basket of supplies index i_b

i_e household economic group index based on living standard costs

i_{e+} household subgroup is the economic group i_e and its subdivisions i_h, i_s, i_a, i_m and i_{ep}.

i_{ep} economic subgroup index for the parents of the main income provider of the household

i_h household composition index for the number of adults and children

i_{hA} identification index for adults within a household eligible and able to work

i_m minority grouping of the main income provider of household

i_o occupation index

i_s employment skill category index of main income provider of household

i_t simulation time index

i_u unpaid productive activities time allocation category that benefit the household

i_v unpaid voluntary time allocation category for household that benefit the community

i_w time in paid work allocation category for household

i_x time in undeclared paid work allocation category of household

j_b household economic subgroup basket of goods and services; a subset of i_b

k_α economy element alternative indexing to i_α

k_b household economic subgroup self-fulfilled goods and services; a subset of j_b

k_{e+} household subgroup alternative indexing to i_{e+}

k_t simulation time index alternative indexing to i_t

n upper limit to index

6.1.2 VARIABLES

μ_α probability of household distribution

π_α inflation measured as a household consumer price index

σ_α ratio or fraction of a financial value of a household

d_α household demand; number of units of goods and services required:

d_α for individual household;

D_α for all households in subgroup, where $D_\alpha = N_\alpha d_\alpha$;

N_α number of households:

N_α in subgroup;

$\underline{N}_\alpha$ in economy element, where $\underline{N}_\alpha = \sum_{i_{e+}=1}^{n} N_{\alpha(i_{e+})}$;

p retail price of a unit of goods and services net of duties and value added tax:

p for supply i_b brand type i_{4b} from retailer i_{5b}, where $p \overset{\text{def}}{=} p_{(i_b[i_{4b},i_{5b}])}$;

P for households in subgroup $i_{6b} = i_{e+}$ based on the probability $\mu_{\alpha(i_b[i_{4b},i_{5b},i_{6b}])}$ of purchasing supplies i_b relative to brand type i_{4b} and retailer outlet i_{5b}, where $P \overset{\text{def}}{=} P_{(i_{e+})} = \sum_{i_{5b}=1}^{n} \sum_{i_{4b}=1}^{n} \mu_{\alpha(i_b[i_{4b},i_{5b},i_{6b}])} p_{(i_b[i_{4b},i_{5b},i_{6b}])}$.

q_α price for a quantity of supplies q_Σ, tax $q_{\alpha T}$ or debt $q_{\alpha D}$:

q_α for individual household;

Q_α for all households in subgroup, where $Q_\alpha = N_\alpha q_\alpha$;

r_D rate of debt interest:

r_D for supply i_b financial service type i_{4b} from retailer i_{5b}, where $r_D \overset{\text{def}}{=} r_{D\,(i_b[i_{4b}, i_{5b}])}$;

R_D for households in subgroup $i_{6b} = i_{e+}$ based on the probability $\mu_{\alpha\,(i_b[i_{4b}, i_{5b}, i_{6b}])}$ of purchasing services i_b relative to product type i_{4b} and retailer outlet i_{5b}, where $R_D \overset{\text{def}}{=} R_{D\,(i_{e+})} = \sum_{i_{5b}=1}^{n} \sum_{i_{4b}=1}^{n} \mu_{\alpha\,(i_b[i_{4b}, i_{5b}, i_{6b}])} r_{D\,(i_b[i_{4b}, i_{5b}, i_{6b}])}$;

s_α household supply; the number of units of supplies being sold:

s_α from individual household;

S_α from all households in subgroup, where $S_\alpha = N_\alpha s_\alpha$;

t time duration

w surrogate model parameter vector

y_α household income:

y_α for individual household;

Y_α for all households in subgroup, where $Y_\alpha = N_\alpha y_\alpha$;

$\underline{Y}_\alpha$ for all households in economy element, where $\underline{Y}_\alpha = \sum_{i_{e+}=1}^{n} Y_{\alpha\,(i_{e+})}$;

z_α household asset z_{α_A} or debt z_{α_D} value:

z_α for individual household;

Z_α for all households in subgroup, where $Z_\alpha = N_\alpha z_\alpha$;

$\underline{Z}_\alpha$ for all households in economy element, where $\underline{Z}_\alpha = \sum_{i_{e+}=1}^{n} Z_{\alpha\,(i_{e+})}$;

6.1.3   SUBSCRIPTS

Δo change in occupation

A asset finances

A_B private business stakeholding asset finances

A_F financial asset finances (such as stocks, bonds and shares in PLCs)

A_{IP} intellectual property rights asset finances

A_L land, property and equipment asset finances

B benefits payment finances

B_{ep} financial support from family contribution to benefit payment finances

D debt finances (negative value relative to income)

D_{SL} secure loan debt finances

D_{UL} unsecured load cash-flow debt finances

D_{UP} unsecured load spread payment purchase finances

ff financial forcing; the remaining income after subtracting household running costs

$F0$ finance agreement start date

L household labour income

L_w labour income from the declared economy

L_x labour income from the undeclared economy

mn minimum household income to maintain a given living standard

pf perceived forcing income; the relative difference in income to a comparison income

rc household running cost accounting for time allocation and the undeclared economy

T tax (positive for cost)

T_γ household property tax (positive for cost)

T_Y household income tax (negative relative to income)

T_V duty and value added tax (positive for cost)

u unpaid productive time equivalent to a volume of goods and services

x undeclared economy

6.1.4   FUNCTIONS

$f_\alpha(\ \ )$ household demographic characteristics surrogate model function

$f_\tau(\ \ )$ tax calculation function

$f_D(\ \ )$ debt repayment calculation function

6.1.5   MATHEMATICAL SYMBOLS

$\sum_{i=1}^{3} x_i$ sum all values of x for index i from 1 to 3,

where $\sum_{i=1}^{3} x_i \ = \ x_1 + x_2 + x_3$

$\begin{cases} x_1 \\ x_2 \\ x_3 \end{cases}$ use value x_1 or x_2 or x_3 as appropriate

6.1.6   EXAMPLE COMPOSITE VARIABLES

$y_{\alpha_{A_B}}$ income (y) of household (α) from private business assets (A_B)

$\underline{Z}_{\alpha_{D_{UL}}}$ economy element (__) value (Z) of household (α) unsecured debt (D_{UL})

6.2   *SURROGATE MODELLING*

The term *surrogate model* is a general name for the group of analytical methods that include machine learning algorithms (such as artificial neural networks), regression fit hypersurfaces (such as radial basis functions) and regression fit statistical models (such as a general linear models). All surrogate models have parameter values populated by training or fitting the model to an existing dataset. Once fitted the model can 'predict' the response of the system that produced the training dataset for a given set of input variable values. Ideally the input variable values must be within the data range of the historical dataset, thus using the surrogate model for interpolation and not extrapolation.

Given a suitable sample size of households within an economy element the financial demographics and the probability of financial decisions for a household within an economic subgroup can be obtained by training a surrogate model against population datasets. The household demographics surrogate model is represented as function $f_\alpha(\ \ )$. Within the brackets are the list of indices that define the variables and dimensions for the pattern fitting model of the surrogate function. The surrogate model parameter vector w is determined by a training process against the population data. Once trained, the surrogate model will provide a single value for each unique set of index values by interrogating the surrogate model using the parameter vector w. The output value from the surrogate model functions for household income, assets and debt will then be factored by the average financial value for the economy element. This will enable the simulation to progress over a series of time steps by only recording changes to the total financial values for each economy element.

6.2.1   DEBT MODEL COMPONENTS

The following surrogate model functions represent household debt components distributed between the household subgroups:

$$z_{\alpha_{D_{SL}(i_\alpha,i_{e+},i_t)}} = f_\alpha(i_\alpha,i_{e+},w)\frac{z_{\alpha_{D_{SL}(i_\alpha,i_t)}}}{N_{\alpha_{(i_\alpha,i_t)}}}$$

is the secured debt of a household within an economic subgroup.

$$z_{\alpha_{D_{UP}(i_\alpha,i_{e+},i_t)}} = f_\alpha(i_\alpha,i_{e+},w)\frac{z_{\alpha_{D_{UL}(i_\alpha,i_t)}}}{N_{\alpha_{(i_\alpha,i_t)}}}$$

is the unsecured debt to spread household payments for specific consumable assets.

$$\bar{z}_{\alpha_{D_{UL}(i_\alpha,i_{e+},i_t)}} = f_\alpha(i_\alpha,i_{e+},w)\frac{z_{\alpha_{D_{UL}(i_\alpha,i_t)}}}{N_{\alpha_{(i_\alpha,i_t)}}}$$

is the unsecured time averaged household debt hold for non-specific cash-flow deficit.

The cost of the debt is calculated as a function of the household debt type and value. The cost of secured debt at each simulation time index i_t is a function of the loan duration $t_{D_{SL}}$, the time index of the loan agreement $i_{t_{F0}}$, the current value of the debt $z_{\alpha_{D_{SL}}}$ and the interest rate of the loan $R_{D_{\alpha_{SL}}}$ either fixed at the agreement time index or variable at the current time index. Therefore, the cost of secured debt can be expressed as

$$q_{\alpha_{D_{SL}(i_\alpha,i_{e+},i_t)}} = f_D\left(-z_{\alpha_{D_{SL}(i_\alpha,i_{e+},i_t)}},R_{D_{\alpha_{SL}(i_\alpha,i_{e+},i_t)}},t_{D_{SL}},i_{t_{F0}}\right)$$

Equation 1. Secured debt cost for household within economic subgroup

For unsecured spread payment debt, the depreciation of the unit supply price P and any value added tax and other duties $q_{\alpha_{T_V}}$ must be accounted for in each time interval throughout the spread payment period $t_{D_{UP}}$ and not at the time index the demand for the supply was fulfilled. The cost of the loan will also be a function of the loan duration $t_{D_{UP}}$, the time index of the loan agreement $i_{t_{F0}}$ and the interest rate of the loan $R_{D_{\alpha_{UP}}}$. Therefore, the cost of unsecured spread payment debt can be expressed as

$$q_{\alpha_{D_{UP}(i_\alpha,i_{e+},i_t)}} = f_D\left(P_{(i_\alpha,i_b,i_{t_{F0}})},q_{\alpha_{T_V(i_\alpha,i_b,i_{t_{F0}})}},R_{D_{\alpha_{UP}(i_\alpha,i_{e+},i_t)}},t_{D_{UP}},i_{t_{F0}}\right)$$

Equation 2. Unsecured spread payment debt cost for household within economic subgroup

The cost of the unsecured loan (interest only) for a household is the average loan value between time steps $\bar{z}_{\alpha_{D_{UL}}}$ factored by the interest rate $R_{D_{\alpha_{UL}}}$. The depreciation of the items consumed within the interval between time steps is accounted for in the costs price of the supply when demanded. Debt repayment is not included due to the nature of the loan. Therefore, the cost of unsecured cash-flow debt can be expressed as

$$q_{\alpha_{D_{UL}(i_\alpha,i_{e+},i_t)}} = -\bar{z}_{\alpha_{D_{UL}(i_\alpha,i_{e+},i_t)}}R_{D_{\alpha_{UL}(i_\alpha,i_{e+},i_t)}}$$

Equation 3. Unsecured cash-flow debt cost for household within economic subgroup

6.2.2 TIME ALLOCATION

Unpaid time for a household may result in them fulfilling their own demand for certain goods and services. The output of the surrogate model will need to represent the probability μ_{α_u} of unpaid time

being allocated to equivalent goods or services i_b, associated with a volume of demand d_{α_u} being fulfilled by the household themselves. Thus,

$$\left[\mu_{\alpha_u}, d_{\alpha_u}\right]_{(i_\alpha, i_b, i_{e+})} = f_\alpha(i_b, i_\alpha, i_{e+}, i_u, w)$$

is the probability of the household reducing demand for supplies by fulfilling the need themselves.

6.2.3 UNDECLARED ECONOMY

Modelling the likelihood of a household purchasing supplies from the undeclared economy must be represented by a probability μ_{α_x} that a volume of goods or services d_{α_x} will be demanded. Thus,

$$\left[\mu_{\alpha_x}, d_{\alpha_x}\right]_{(i_\alpha, i_b, i_{e+})} = f_\alpha(i_b, i_\alpha, i_{e+}, w)$$

is the probability of the household purchasing a volume of goods or services from the undeclared economy.

6.2.4 INCOME COMPONENTS

The following surrogate model functions represent the household income components for the economic subgroups within an economy element:

$$y_{\alpha_{Lw\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, i_w, w)\frac{Y_{\alpha_{Lw\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is the household income for time spent in paid employment within the declared economy.

$$y_{\alpha_{Lx\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, i_x, w)\frac{Y_{\alpha_{Lx\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is the household income for time spent in paid employment within the undeclared economy.

$$y_{\alpha_{AL\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, w)\frac{Y_{\alpha_{AL\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is land asset income for the household from leasing property, equipment or land or capital gains from the sale of property, equipment or land.

$$y_{\alpha_{AF\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, w)\frac{Y_{\alpha_{AF\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is financial asset income for the household, from dividends or capital gains from the sale of bonds, stocks and shares in public companies.

$$y_{\alpha_{AB\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, w)\frac{Y_{\alpha_{AB\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is the household private business income from dividends (or profit sharing) or capital gains from the sale of a private business stakeholding.

$$y_{\alpha_{AIP\,(i_\alpha, i_{e+}, i_t)}} = f_\alpha(i_\alpha, i_{e+}, w)\frac{Y_{\alpha_{AIP\,(i_\alpha, i_t)}}}{N_{\alpha_{(i_\alpha, i_t)}}}$$

is the household intellectual property rights IPR income from royalties (or capital gains) to use (or own) patent rights for an invention

or to use (or own) copyrights for creative works.

$$y_{\alpha B(i_\alpha, i_{e+}, i_t)} = f_\alpha(i_\alpha, i_{e+}, i_w, w) \frac{Y_{\alpha B(i_\alpha, i_t)}}{N_{\alpha(i_\alpha, i_t)}}$$

is the household benefit income, including employment benefits, child support, state pensions and financial support from family.

The total household income for labour is the sum of declared income (gross of tax) and undeclared income within an economy element i_α for the economic subgroup i_{e+} at simulation time index i_t. Therefore, the total household income for labour can be expressed as

$$y_{\alpha L(i_\alpha, i_{e+}, i_t)} = y_{\alpha L_w(i_\alpha, i_{e+}, i_t)} + y_{\alpha L_x(i_\alpha, i_{e+}, i_t)}$$

Equation 4. Total declared and undeclared labour income of household within economic subgroup

Total household income from assets is the sum of the income from land, financial, business and intellectual property assets and is expresses as

$$y_{\alpha A(i_\alpha, i_{e+}, i_t)} = y_{\alpha A_L(i_\alpha, i_{e+}, i_t)} + y_{\alpha A_F(i_\alpha, i_{e+}, i_t)} + y_{\alpha A_B(i_\alpha, i_{e+}, i_t)} + y_{\alpha A_{IP}(i_\alpha, i_{e+}, i_t)}$$

Equation 5. Asset income of household within economic subgroup

6.2.5 ASSET DISTRIBUTION

Information on the assets owned by households within an economic subgroup will be derived from population data and will need to be considered in dynamic models of the economy. The following surrogate functions represent the household assets within an economic subgroup:

$$z_{\alpha A_L(i_\alpha, i_{e+}, i_t)} = f_\alpha(i_\alpha, i_{e+}, w) \frac{Z_{\alpha A_L(i_\alpha, i_t)}}{N_{\alpha(i_\alpha, i_t)}}$$

is the value of land, property and depreciable assets for a household within an economic subgroup.

$$z_{\alpha A_F(i_\alpha, i_{e+}, i_t)} = f_\alpha(i_\alpha, i_{e+}, w) \frac{Z_{\alpha A_F(i_\alpha, i_t)}}{N_{\alpha(i_\alpha, i_t)}}$$

is the value of bonds, stocks and shares in publicly traded companies for a household within an economic subgroup.

$$z_{\alpha A_B(i_\alpha, i_{e+}, i_t)} = f_\alpha(i_\alpha, i_{e+}, w) \frac{Z_{\alpha A_B(i_\alpha, i_t)}}{N_{\alpha(i_\alpha, i_t)}}$$

is the value of private business stakeholding for a household within an economic subgroup.

$$z_{\alpha A_{IP}(i_\alpha, i_{e+}, i_t)} = f_\alpha(i_\alpha, i_{e+}, w) \frac{Z_{\alpha A_{IP}(i_\alpha, i_t)}}{N_{\alpha(i_\alpha, i_t)}}$$

is the value of intellectual property rights for a household within an economic subgroup.

6.3 HOUSEHOLD ECONOMICS

This section defines the functions in the sequence of analysis required to evaluate the financial decisions of a household.

6.3.1 RUNNING COST

The minimum income required for a given living standard $y_{\alpha_{mn}}$ is the sum of the price of goods and services in an economy element i_α for each economic subgroup i_{e+} including value added tax and other duties $q_{\alpha_{TV}}$ at the simulation time index i_t plus local taxes such as property tax $q_{\alpha_{T\gamma}}$. The cost of the good or service must account for being paid outright or being spread through a secured loan repayment contract $q_{\alpha_{D_{SL}}}$ or through an unsecured loan repayment agreement $P_{\alpha_{D_{UP}}}$. Therefore, the minimum income for a giving living standard can be expressed as

$$y_{\alpha_{mn(i_\alpha,i_{e+},i_t)}} = \sum_{j_{b(i_{e+})}=1}^{n} \begin{cases} d_{\alpha(i_\alpha,j_b,i_t)}P_{(i_\alpha,j_b,i_t)} + q_{\alpha_{TV(i_\alpha,j_b,i_t)}} \\ q_{\alpha_{D_{SL}(i_\alpha,j_b,i_{e+},i_t)}} \\ q_{\alpha_{D_{UP}(i_\alpha,j_b,i_{e+},i_t)}} \end{cases} + q_{\alpha_{T\gamma}}$$

Equation 6. Household minimum income to maintain living standard

The running costs of a household $y_{\alpha_{rc}}$ can be reduced by unpaid household labour fulfilling their own demand for services and goods $d_{\alpha_u}P_u$ or by purchasing goods and services from the undeclared economy $d_{\alpha_x}P_x$. The household running costs will need to correct the minimum living standard income $y_{\alpha_{mn}}$ by replacing the price of specific supplies with the alternative cost and it must reflect purchasing patterns that are not in keeping with the minimum income index $j_{b(i_{e+})} \Rightarrow k_{b(i_{e+})}$. Therefore, the household running cost can be expressed as

$$y_{\alpha_{rc(i_\alpha,i_{e+},i_t)}} = y_{\alpha_{mn(i_\alpha,i_{e+},i_t)}}$$
$$- \sum_{j_{b(i_{e+})}=1}^{n} \begin{cases} d_{\alpha_{u(i_\alpha,j_b,i_{e+})}}P_{u(i_\alpha,j_b,i_{e+})} + \dfrac{d_{\alpha_{u(i_\alpha,j_b,i_{e+})}}}{d_{\alpha(i_\alpha,j_b,i_t)}}q_{\alpha_{TV(i_\alpha,j_b,i_t)}} \\ d_{\alpha(i_\alpha,j_b,i_t)}P_{(i_\alpha,j_b,i_t)} + q_{\alpha_{TV(i_\alpha,j_b,i_t)}} - d_{\alpha_{x(i_\alpha,j_b,i_{e+})}}P_{x(i_\alpha,j_b,i_t)} \\ d_{\alpha(i_\alpha,j_b,i_t)}P_{(i_\alpha,j_b,i_t)} + q_{TV(i_\alpha,j_b,i_t)} - d_{\alpha(i_\alpha,k_b,i_t)}P_{(i_\alpha,k_b,i_t)} - q_{\alpha_{TV(i_\alpha,k_b,i_t)}} \end{cases}$$

Equation 7. Household running cost to maintain living standard

6.3.2 INCOME

The income of a household y_α is the sum of the total salary for paid labour y_{α_L}, total return on assets y_{α_A} and total value of benefit payments y_{α_B}, which are derived from population data and are discussed in Section 6.2.4. Income tax $q_{\alpha_{T_I}}$ (discussed below) and cash-flow debt interest payments $q_{\alpha_{D_{UL}}}$ (discussed in Section 6.2.1) are subtracted from the total household income. Thus,

$$y_{\alpha(i_\alpha,i_{e+},i_t)} = y_{\alpha_{L(i_\alpha,i_{e+},i_t)}} + y_{\alpha_{A(i_\alpha,i_{e+},i_t)}} + y_{\alpha_{B(i_\alpha,i_{e+},i_t)}} - q_{\alpha_{TY(i_\alpha,i_{e+},i_t)}} - q_{\alpha_{D_{UL}(i_\alpha,i_{e+},i_t)}}$$

Equation 8. Income for household within an economic subgroup

The cost of household income tax $q_{\alpha_{T_Y}}$ is dependent on the declared pay for labour $y_{\alpha_{L_W}}$, the treatment of asset income from land $y_{\alpha_{A_L}}$, finance $y_{\alpha_{A_F}}$, private business $y_{\alpha_{A_B}}$ and intellectual property $y_{\alpha_{A_{IP}}}$ and benefit income y_{α_B}. The household income tax can be expressed as a tax function

$$q_{\alpha_{T_Y(i_\alpha, i_{e+}, i_t)}} = f_\tau\left(i_\alpha, i_{e+}, i_t, y_{\alpha_{L_W}}, y_{\alpha_{A_L}}, y_{\alpha_{A_F}}, y_{\alpha_{A_B}}, y_{\alpha_{A_{IP}}}, y_{\alpha_B}\right)$$

Equation 9. Cost of income tax for household within an economic subgroup

6.3.3 FINANCIAL FORCING

The financial forcing of a household $y_{\alpha_{ff}}$ is the difference between the income y_α and the running costs $y_{\alpha_{rc}}$. Therefore, the household financial forcing can be expressed as

$$y_{\alpha_{ff(i_\alpha, i_{e+}, i_t)}} = y_{\alpha(i_\alpha, i_{e+}, i_t)} - y_{\alpha_{rc(i_\alpha, i_{e+}, i_t)}}$$

Equation 10. Financial forcing income for household within an economic subgroup

6.3.4 PROBABILITY OF RECEIVING AN UNSECURED LOAN

If a household has a negative financial forcing then the probability that a household will obtain an unsecured loan to bridge the cash-flow short fall must be assessed using a surrogate model type methodology. Thus,

$$\mu_{\alpha_{D_{UL}}} = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha_{ff}}, w\right)$$

is the probability that a household can obtain an unsecured loan.

6.3.5 PERCEIVED FORCING

A household subgroup that does not experience negative financial forcing may have their financial decisions driven by a perceived forcing, which could lead to looking for a new job, a change in time allocation or a change in the supplies (including assets) being bought and sold. The perceived forcing could be a comparison with the previous annual income $y_{\alpha(i_\alpha, i_e, k_t)}$ factored by a measure of household consumer inflation π_α (such as ONS.Gov.UK, 2019 [1]) or by comparison with the income of colleagues and acquaintances $y_{\alpha(i_\alpha, k_{e+}, i_t)}$ or by comparison of the salaried income paid within another economy element $y_{\alpha_{L_W(k_\alpha, i_{e+}, i_t)}}$. Therefore, the perceived forcing can be expressed as

$$y_{\alpha_{pf(i_\alpha, i_{e+}, i_t)}} = \begin{cases} y_{\alpha(i_\alpha, i_{e+}, i_t)} - y_{\alpha(i_\alpha, i_{e+}, k_t)}\pi_\alpha \\ y_{\alpha(i_\alpha, i_{e+}, i_t)} - y_{\alpha(i_\alpha, k_{e+}, i_t)} \\ y_{\alpha_{L(i_\alpha, i_e, i_t)}} - y_{\alpha_{L(k_\alpha, i_{e+}, i_t)}} \end{cases}$$

Equation 11. Perceived forcing based on previous income

6.3.6 PROBABLE HOUSEHOLD FINANCIAL DECISIONS

The financial forcing $y_{\alpha_{ff}}$ and the perceived forcing $y_{\alpha_{pf}}$ will affect financial decisions. With a sufficiently large sample size of households, it is anticipated that the varied financial options available

to households within an economic subgroup can be captured over time from real data for economy elements to train the surrogate model parameter vector w. The response of the household to a given income forcing can then be modelled as the proportion of households within an economic subgroup undertaking a given action. The output of the surrogate model will need to represent the probability μ_{α_F} of buying supplies and assets or selling depreciable assets and assets in the economy basket of goods i_b, along with the volume of supplies to be sold s_α or purchased d_α. Thus,

$$\left[\mu_{\alpha_F}, s_\alpha, d_\alpha\right]_{(i_b)} = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha ff}, y_{\alpha pf}, t_{ff}, w\right)$$

is the proportion of households within an economic subgroup selling or purchasing a volume of supplies.

To model households planning to make changes to the source(s) of salaried income, a surrogate function must be created to determine the probability that an adult within a household is actively seeking new employment $\mu_{\alpha_{\Delta o}}$ where the adult within the household is determined by using index i_{hA}. Thus,

$$\mu_{\alpha_{\Delta o\,(i_{hA})}} = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha ff}, y_{\alpha pf}, w\right)$$

is the proportion of households within an economic subgroup with a specific adult seeking new or additional work.

For households with surplus income a function is required to determine the probability $\mu_{\alpha_{y_\alpha}}$ that a household donates a fraction of its income $\sigma_{y_{\alpha ff}}$ to charity $i_{b\,(i_{C+})}$, the probability that a household $\mu_{\alpha_B\,ep}$ gives money to family $y_{\alpha_B\,ep}$ and the probability that a household μ_{α_M} saves a portion of surplus income $\sigma_{y_{\alpha ff}}$ as cash or other instant access form. Therefore, the probability functions are as follows:

$$\left[\mu_{\alpha_{y_\alpha}}, \sigma_{y_{\alpha ff}}\right]_{\left(i_{b(i_{C+})}\right)} = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha ff}, w\right)$$

is proportion of households within an economic subgroup donating a proportion of surplus income to charity.

$$\left[\mu_{\alpha_B\,ep}, y_{\alpha_B\,ep}\right]_{(i_{ep})} = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha ff}, w\right)$$

is the proportion of households within an economy subgroup giving financial support to family.

$$\left[\mu_{\alpha_M}, \sigma_{y_{\alpha ff}}\right] = f_\alpha\left(i_\alpha, i_{e+}, y_{\alpha ff}, w\right)$$

is proportion of households within an economic subgroup retaining surplus income in an instant access form.

7   DISCUSSION

The household decision-making model proposed here is not claimed to be a complete solution, but a starting point for further development or for substitution with existing theories. The Economy Dynamics framework will be developed to enable adaptable simulation setup so that a forecaster can substitute any microeconomic model with any other equivalent methodologies. Household income forcing is a framework that provides a context to the gathering, analysis and interpretation of data. It is based on the common understanding of 'disposable income' – in other words the difference between household income and household running costs. This means that household financial

behaviour is not dependent on absolute wealth but on a relative measure of income. A household on a low income with all their needs met and a little income spare can have greater contentment than a wealthy household living beyond the means of their income. Consumer contentment could be reflected by certain characteristics in their financial choices, which can be explored within this framework. Household income forcing can be amended, revised or replaced as further information about the context of household spending arises, or according to the preferences of a forecaster.

Household income forcing will be able to quantify welfare using both the binary measure of households moving above or below the poverty threshold, and the level of negative financial forcing across a full range of household economic subgroups for a set of fiscal and monetary policies or economic events. It provides a framework by which the actions of households under equivalent economic conditions can be analysed. It has broad implications for the potential quantification of welfare and quality of life within an economy. For example, households that choose not to increase their living standard may give money to charity or family, have large long-term bank deposits or purchase unusual assets. Some such households could then be identified as satiated consumers. Studying satiated household groups will establish metrics that can be used to assess the quality of life within economic regions based on markers of consumer satiation. The metrics could include the probability of a household donating a proportion of their income to charity, or the probability of a household volunteering time to charitable activities.

8   FURTHER WORK

The household income forcing is a framework for modelling household financial behaviour. The aim of discretising the economy into elements and households into distinct subgroups is to maximise the fit of the surrogate models to the historical datasets of population financial behaviour. Collecting population data in a form consistent with the household income forcing framework is needed. However, this is a substantial undertaking and will require collaboration with organisations that are experienced at collating population economic statistical data and could support the development of the behavioural surrogate models and define the supplies object and the occupational index. The approach then requires testing against the behavioural patterns of population data within different economic regions that have not been used for training the surrogate models.

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10 DOCUMENT INFORMATION

REVISION NOTES

Addition of Section 1.2 to explain why a new model of household decision making is important.

DOCUMENT REFERENCE

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KEYWORDS

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